Application

for

United States Patent

To all whom it may concern:

Be it known that,

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have invented certain new and useful improvements in

CO_2/O_2 INCUBATOR PREDICTIVE FAILURE FOR CO_2 AND O_2 SENSORS

of which the following is a full, clear and exact description:

CO_2/O_2 INCUBATOR PREDICTIVE FAILURE FOR CO_2 AND O_2 SENSORS

FIELD OF THE INVENTION

The present invention relates generally to the prediction of failure of sensors within a controlled gas atmosphere enclosure. More particularly the present invention concerns methods and apparatus for the prediction of failure of O_2 and CO_2 sensors within an incubator environment.

BACKGROUND OF THE INVENTION

There are a number of commercial applications for controlled gas atmosphere enclosures including incubators. For example, electrical components and circuits are often tested in enclosures at a selected temperature and/or relative humidity for a period of time. Another common application for controlled atmosphere enclosures is the growth of biological cultures in a laboratory. As will be discussed herein with regard to a particular embodiment, the present invention may be advantageously employed in connection with a controlled gas atmosphere incubator in which a chamber for biological cultures is heated and in which the atmosphere of the chamber is controlled as to one or more constituent gases and/or the relative humidity.

A typical enclosure of the foregoing type includes a generally cubical outer housing made up of five insulated walls (top, bottom, left side, right side, and rear) and an insulated front door. The door is mounted on hinges on the front of one of the side walls and may be opened to permit access to the interior of the incubator. When the door is closed, it is suitably sealed about its periphery to the housing walls to form the sixth wall of the housing. The incubator chamber, in which biological cultures are grown, is formed by inner walls, inside the insulated outer walls, and typically includes shelves upon which culture containers are placed. The shelves are carried by suitable shelf supports inside the chamber.

Most incubators of this type are either water jacket incubators or forced draft incubators. In a water jacket incubator the inner chamber is heated to the desired temperature by a sealed jacket of water surrounding the five fixed sides of the incubator chamber. The water jacket lies between the chamber wall and the insulated housing walls and is heated by heating elements in thermal contact with the water in the water jacket. Due to the thermal conductivity of water, the heat from the individual heating elements is relatively evenly dispersed through the water in the water jacket, providing even heating of the chamber. Such even heating is desirable in order to provide a uniform temperature for the biological cultures in different areas within the chamber and in order to prevent "cold spots" on the inner chamber wall upon which condensation can form.

Although the heating of the chamber walls in a water jacket incubator is substantially uniform, the chamber atmosphere will stratify thermally if the chamber atmosphere is undisturbed. When such stratification occurs, the temperature of the chamber atmosphere is greater at the top of the chamber than at the bottom of the chamber. In addition, if a constituent gas concentration is maintained in the chamber, such as a particular CO_2 level, the constituent gas will also stratify within the chamber atmosphere. Consequently, it is desirable to maintain a certain rate of flow of gas within the chamber to assure uniformity of temperature and of constituent gases. In order to do this, typically a portion of the chamber is separated from the main chamber area by a wall to define a duct extending, for example, along a side of the chamber. A small blower or fan is placed in the duct and the chamber atmosphere is circulated, such as from a duct inlet in the upper portion of the chamber to a duct outlet in a lower portion of the chamber.

In a forced draft incubator, the inner chamber walls are insulated from the outer housing walls by a layer of insulation inside the housing walls. However, in this case there is no water jacket interposed between the insulated outer walls and the inner chamber walls. To obtain heating of the chamber in a forced draft incubator, some type of duct, such as described above, is typically provided within the chamber, and a fan and a heating element are mounted in the duct. As the fan circulates air from the main chamber area through the duct, the circulated chamber atmosphere is heated by the heating element. In order to heat the chamber atmosphere substantially uniformly, and to the desired temperature, considerably greater air flow is required than in the case of a water jacket incubator.

In a typical forced draft incubator, or water jacket incubator, if a constituent gas in the atmosphere of the incubator chamber is to be maintained at a particular level, a probe is introduced into the chamber, perhaps within the duct through which the chamber atmosphere circulates. In the case of CO_2, for example, a CO_2 sensor is introduced into the incubator chamber to measure the concentration of CO_2 therein. A source of CO_2 is then coupled to the interior of the chamber through a controlled valve, with an automatic control system actuating the valve as required to maintain the CO_2 concentration in the chamber at a selected level.

The humidity in a forced draft incubator is also often controlled. Rather than introducing steam or water into the incubator chamber as may be done in the case of a water jacket incubator, in a forced draft incubator quite often a pan of water is placed upon the floor of the incubator chamber, and the recirculated chamber atmosphere is directed out of the bottom of a duct across the surface of the water in the pan. Due to the higher recirculation rates in a forced draft incubator, appropriate humidification of the chamber is obtained.

In either a forced draft or a water jacket incubator, sensors such as for CO_2 or humidity have typically been located within the chamber atmosphere itself, although perhaps within a recirculation duct, as earlier described. Such sensors in the chamber are subject to the chamber atmosphere, and a sensor can fail or suffer performance degradations due to contaminants or the accumulation of a coating on the sensor. The presence of such sensors in the incubator chamber itself also makes cleaning of the chamber interior more difficult. In fact, the very existence of a duct or the like for the circulation of the chamber atmosphere within the chamber introduces difficulties in cleaning the chamber.

The recirculation of the chamber atmosphere, such as through a duct, in either type of incubator presents yet another problem, that of potential contamination of biological cultures within the chamber. Contaminants such as mold spores are almost invariably present in the chamber atmosphere and may be directed by the recirculatory air flow into the biological culture containers.

Culture contamination problems are exacerbated by the higher air flows required in forced draft incubators.

Higher air flow rates involved in forced draft incubators have a further disadvantage in that the higher flow rates tend to dry out biological culture media. To a large degree, the necessity of offsetting this desiccation results in the requirement for humidity control in forced draft incubators. In such incubators, a relatively high humidity is maintained so that the drying effect of the gas flow is ameliorated.

Furthermore, a well known problem with incubator systems is that it is difficult to know when a pending failure of the O_2 and CO_2 sensors may occur. Incubators are typically used for growing cultures in a controlled environment wherein both temperature and atmospheric gas concentration are maintained at selected levels. For certain applications it is highly desirable to have both temperature and gas concentrations maintained within strict tolerances while still allowing easy access to the incubator chamber for adding or removing items to and from the chamber or for inspecting the contents of the chamber. Control of environmental variables is desirable to maintain accuracy and reproducability of incubation results.

Therefore, it would be desirable to provide an incubator having the ability to provide a warning of a pending failure of the O_2 and CO_2 sensors mounted therein.

SUMMARY OF THE INVENTION

The foregoing needs have been satisfied to a great extent by the present invention wherein, this invention includes the formulation of algorithms utilized for early warning of O_2 and/or CO_2 sensors. The algorithms are included in the firmware for an embedded controller and operate to analyze the sensors for lifetime adjustment every hour as determined by the cumulative clock within the controller. As an hour roll-over occurs, the sensor lifetime value is adjusted and normalized to an hour count stored in $\%O_2$ lifetime hours used at 20 °C. The normalization includes assumptions that the O_2 concentration and the O_2 sensor temperature remained constant over the previous hour.

It is accordingly an object of the present invention to provide a predictive warning system of pending sensor life failure.

There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows may be better understood, and in order that the present contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described below and which will form the subject matter of the claims appended hereto.

In this respect, before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein, as well as the abstract, are for the purpose of description and should not be regarded as limiting.

As such, those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for the designing of other structures, methods and systems for carrying out the several purposes of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a preferred embodiment of the present invention showing a microcontrolled system with O_2 and CO_2 sensors, an embedded controller and a power board.

Figure 2 shows a user interface indicating the variables of temperature, CO_2 and O_2 in an incubator environment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Referring now to the figures, FIG. 1 illustrates a microcontroller based system **10**, an embedded controller **20**, O_2 sensor **25**, CO_2 sensor **35**, and a power board **30** which are set in an incubator cabinet **40**. This microcontroller based system **10** has the ability to track the O_2 and the CO_2 set point, in percentage, along with the operation time. O_2 sensor **25** may be specified to perform for 900,000 O_2 percentage hours. Thus, it is a straightforward calculation to determine how close the system is coming to 900,000 O_2 percentage hours. In the case of a CO_2 sensor **35**, for example, the CO_2 sensor **35** can be introduced into the incubator cabinet **40** to measure the concentration of CO_2 present therein. A source of CO_2 (not shown) is then coupled to the interior of the incubator cabinet **40** through a controlled valve (not shown), with an automatic control system (not shown) which may include the embedded controller **20** actuating the valve as required to maintain the CO_2 concentration in the incubator cabinet **40**.

Such sensors as the O_2 sensor **25** and CO_2 sensor **35** in an incubator cabinet **40** may be subject to the incubator cabinet **40** internal atmosphere, and these sensors can fail or suffer performance degradations due to contaminants or the accumulation of a coating on the sensor over time.

Referring to FIG. 2, it would be highly beneficial to the user to be forewarned of this pending threshold. For instance, at some predetermined value, say 800,000 O_2 percentage hours, the user would begin to see a warning on interface display **50**, such as "Replace O_2 sensor, P/N XXXXXX."

A similar scenario holds true for CO_2 sensor **35** with respect to percentage hours and lifetime use. The main difference between CO_2 sensor **35** from the O_2 sensor **25** is that the operational life would be based on the warranty period of the CO_2 sensor **35**: the time that it is guaranteed to operate correctly by the manufacturer. Again, the system is capable of tracking the operation time of CO_2 sensor **35** as well.

Similar interface display **50** notices will also be provided for re-calibration times for both sensors.

O_2 Sensor Life Detailed Example

The O_2 sensor lifetime is dependent on two variables, temperature and O_2 concentration. Interfacing an O_2 sensor **25** to an embedded controller **20** designed to control temperature and O_2 (among other parameters) as aforementioned allows the lifetime usage of the sensor to be monitored and ultimately can warn a user of impending sensor replacement. The preferred embodiment analyzes the sensor for lifetime adjustment every hour as determined by the cumulative clock within the controller **20**. As the hour roll-over occurs, the sensor lifetime value is adjusted and normalized to an hour count stored in %O_2 lifetime hours used at **20** °C. The normalization includes assumptions that the O_2 concentration and the O_2 sensor temperature remained constant over the previous hour. Although this assumption may at first appear invalid, 1) an incubator application typically holds parameters constant for long periods of time, 2) it is easily adapted to a different application, and 3) the O_2 sensor life hours count is a large number (thus if small numbers of the hour roll-overs are inaccurate it will not effect the final result). The following code snippet is an excerpt from the firmware in the embedded controller **20** that executes every hour to increase the O_2 sensor lifetime:

Code Snippet (executes every hour):

```
O2SensorLifeUsed20C =
+=(float)(((float)(O2Act/10.0))*((float)(100.0/(1192.0/(exp(2.0+(0.0239*(
Temp/10.0))))))));

O2Act = 10 * percentage O2
Temp =  10 * temperature (°C).
```

Example:

O2Act = 250 (25% O_2)
Temp = 370 (37.0 °C)
O2SensorLifeUsed += 37.523

Therefore, for this particular hour adjustment the sensor life utilized over the last hour was 37.523 for the sensor at 25% O_2 and 37.0 °C. It should be noted that the transfer function above may be different for other O_2 sensors **25** and that the preferred embodiment utilizes self-powered, diffusion limited, metal-air battery types.

At this point the embedded code could compare the variable O2SensorLifeUsed20C with another variable that represents the total $\%O_2$ lifetime hours used at 20 °C. When the O2SensorLifeUsed20C is greater than the $\%O_2$, it is time to replace the sensor and the system can respond through the interface display **50**.

In an actual application, the number may be padded to allow for time for the user of the device to receive a warning prior to expiration. Furthermore, the embedded user interface display **50** should allow a reset interface **60** to re-zero the count for in the field sensor replacement.

The above description and drawings are only illustrative of preferred embodiments which achieve the objects, features, and advantages of the present invention, and it is not intended that the present invention be limited thereto. Any modification of the present invention which comes within the spirit and scope of the following claims is considered to be part of the present invention.